Fire-Tube Boiler Asset Care and Maintenance Guide

An Essential Reference for Improving Boiler Safety and Reliabilty

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Preface

The motivation to develop this book arose from the desire to develop a practical reference source for engineers, operators, inspectors, and maintenance personnel that would enable them to gain a greater understanding of the causal factors responsible for different types of problems, which can compromise the safety and operational reliability of fire-tube boilers. The author has been directly involved with many routine inspections and investigations of fire tube boilers which have failed in either a disruptive or catastrophic manner.

The book contains a wealth of information and practical advice which can be used to develop and support a Condition-Based Maintenance programme. The book contains a diverse collection of images and photographs of different types of failures and other problems that continue to crop-up time and time again in fire-tube boilers.

- Includes many examples of fatigue and corrosion-related failures.
- Gives guidance on how, when and where to inspect fire-tube boilers
- Gives guidance on how to repair fire-tube boilers which have suffered fatigue cracking and/or corrosion.
- Contains many tips and practical advice on how to improve boiler safety and reliability.
- An essential training resource for boiler operators and inspectors.

The first three chapters provide background information about the scope of the book and the current statutory and non-statutory inspection requirements for this type of boiler. Chapter four gives a brief introduction to boiler design in order to familiarise the reader with the different types of construction that can be found in use today. Chapters six and seven deal with the different types of problems and degradation mechanisms that can be encountered with each type of boiler. Chapter eight provides a detailed insight as to how and when this type of boiler should be inspected and how the inspections should be integrated into a Condition Monitoring programme. Chapter nine gives examples of different types of repairs in order to enable the owner or operator of a fire-tube boiler to improve its reliability by implementing more cost-effective and reliable repairs. Chapter ten gives tips and advice on boiler maintenance which can be used to make boilers safer and more reliable. Chapter eleven contains a list of useful references that relate to the design, construction, inspection and maintenance of fire-tube boilers.

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www.guerin.ie

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Northamptonshire, United Kingdom
www.lmp.co.uk

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The Safety Assessment Federation, London, United Kingdom.
www.safed.co.uk

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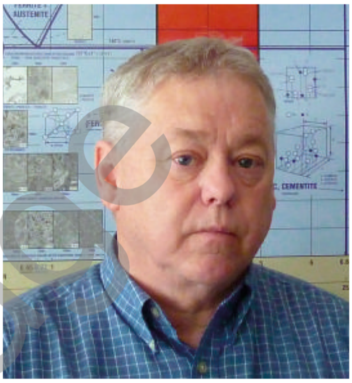
www.flyingzonedirect.co

Final thanks go to Enspec Engineering (UK) Ltd who have provided the author with the time and financial resources to develop this publication. The majority of the information contained within the book has been extracted from Enspecs' vast database of case histories and other archived material.

Malcolm Nicol

About the Author



Malcolm Nicol is a scientist/engineer, consultant and author of technical books with more than thirty years experience with the inspection of process plant and equipment and, the investigation and analysis of engineering failures in the chemicals, foods, pharmaceuticals and biotechnology industries. He has performed many forensic engineering investigations of both disruptive and catastrophic failures which have caused major damage to critical plant and equipment and interruptions to manufacturing operations.

Malcolm started his working career in 1971 at Shell UK Ltd where he began his career as a chemical plant technician. In 1973 he joined Unilever Research at their Port Sunlight laboratory where he initially worked in the Chemical Processing section. He then transferred to the Materials and Corrosion section at Port Sunlight which was later renamed Reliability Engineering, to reflect its gradually expanding role as a provider of technical troubleshooting support services for the company. During this time he was fortunate to receive extensive training and experience development as a Plant Inspector working with a dedicated team of engineers and technicians responsible for the inspection and integrity assessment of critical process plant and equipment at Unilever factories around the world. In addition to learning about the many analytic techniques used for investigating materials-related failures, Malcolm became proficient with the non-destructive test methods that are employed extensively for the condition assessment of pressure vessels and other high value capital plant items.

In 1988, he left Unilever to start a new company called Engineering Inspection and Reliability Ltd, which later became known as Enspec Engineering (UK) Ltd. The company has been trading for approximately twenty four years up to the publication of this book, during which time it has built-up a vast database of reports and case histories relating to the inspection of plant and equipment in a wide range of industries. In addition to his role as Managing Director for Enspec, Malcolm is carrying out research into the corrosion of stainless steel hygienic and aseptic process systems.

Chapter
1

Introduction

This book provides an invaluable source of information relating to a wide variety of technical issues that continue to crop up time and time again in fire-tube boilers. The information it contains can be used to solve technical problems and improve overall reliability and safety of the equipment.

Experience has shown that problems such as corrosion and fatigue cracking can occur in a variety of areas in boilers that have been in service for many years, and even new boilers where there has been a departure from the normal operating conditions. Improvements to boiler design and manufacturing methods over the years have certainly reduced the risk of major failures occurring, although even modern boilers manufactured to a high standard will eventually suffer some form of material degradation. It is Enspecs' experience that all boilers develop some form of corrosion and/or cracking-related problems during their operational life.

The information and advice contained within the book is of a practical rather than academic nature making it a more user-friendly tool for investigating boiler-related problems.

It is ideal for those companies that already have optimum in-house maintenance/inspection procedures in place, but want to develop their knowledge further as part of a Continuous Improvement process.

The book will also be of benefit to those companies that do not have the resources and expertise available locally, but want to improve their standards of maintenance and plant reliability by utilising the knowledge and experience of companies like Enspec.

Boiler users will be able to use the information in order to resolve problems such as leakages from smoke tubes or fatigue cracking inside a fire-tube The book gives step by step advice to establish the root cause of a problem and practical information regarding the development of a cost-effective repair or replacement solution. The information it contains will also enable the operator to make a more accurate assessment of a problem, rather than having to rely too heavily on the advice of a sub-contractor.

The book is also a potentially useful source of information for inspectors engaged in the inspection of fired pressure vessels. It contains important information about what level of inspection should be employed and what non-destructive test methods should be used to find certain types of critical defects

Please note

There are a number of Key Points and Tips ***highlighted in italic*** which are in the opinion of the author, considered to be particularly important. They have been included to assist the user to identify a particular condition or potential problem area.

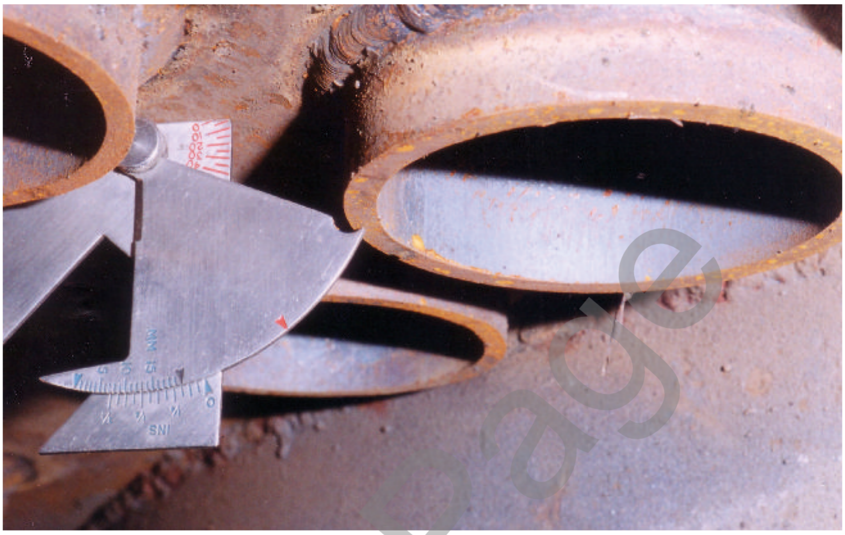


Figure 6.15 Smoke tube overprotrusion in the front end plate of a new boiler. Note:- This was a manufacturing non-comformity where the tube extension exceeded the maximum limit for the construction code.

Influence of Overprotrusion Geometry on Heat Flow

Modern boilers are fabricated with plain/stay tubes that are fitted with the tube ends being either flush with the tube plate, or slightly protruding up to a maximum of 3 mm, although in some boilers the height of protrusion may exceed 3 mm as a result of a manufacturing non-conformity. In older boilers with an inherently poorer standard of construction, there has been less control over the degree of tube extension that has resulted in a tendency for the tube end and weld to overheat and eventually crack. It is becoming common practice now for boilers which have partial penetration welds to slightly radius the tube end to improve hot gas flow and reduce the stress concentration effect further.

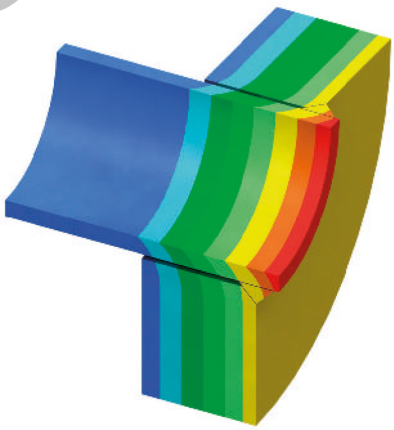


Figure 6.16 Typical isothermal plot for a protruding smoke tube end. Note:- Temperature ranges shown are approximate only as they will vary depending on the boiler operating conditions.

Key	T°C
🟥	441+
🟧	421-440
🟨	401-420
🟩	381-400
🟩	341-380
🟩	321-340
🟦	301-320
🟦	280-300

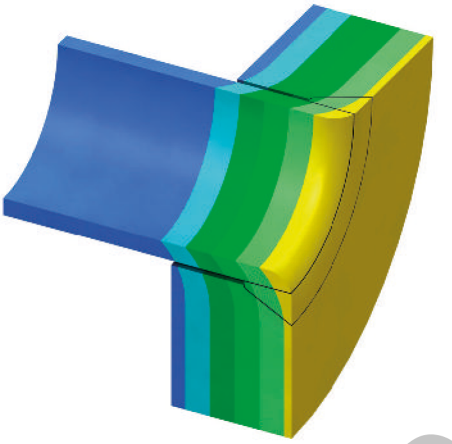


Figure 6.17 Typical isothermal plot for a flush and radiused tube end showing a more evenly distributed heat flow and lower tube end temperature.

Cracking Associated with Smoke Tube Overprotrusion

Overheating can occur on the protruding smoke tubes leading to oxidation of the metal and radial cracking which normally initiates on the corner of the tube end as shown below in Figure 6.18. Cracks may also initiate from the 'root' of the weld and propagate through the tube wall as shown in Figure 6.19.

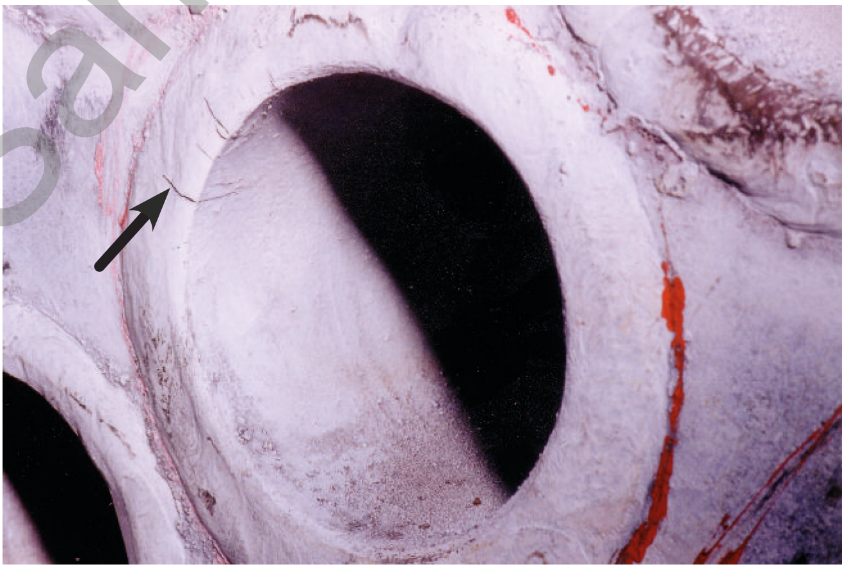


Figure 6.18 Typical form of cracking (arrowed) on the smoke tube ends.

- Automatic firing controls that control the fuel supply to the burner, and can shut-off when the water level falls to a pre-determined point below the normal operating level. The control should also be fitted with an audible alarm should this condition arise.

- Independent overriding control which can cut off the fuel supply to the burner and sound an audible alarm when the water level falls to a pre-determined low level. The control system should be designed so that it has to be manually reset before the boiler can be brought into operation.

Key points:

1. The steam and water legs of water gauges should be blown through separately at least every eight hours of normal operation to ensure that they are clear of any solids. Control chamber connections should also be blown down at least once per day or shift.

2. It is strongly recommended that a record of all blowdown tests be maintained together with information regarding any maintenance of controls, etc.

Reference:

[1] PM5 Guidance note for Automatically Controlled Steam and Hot Water Boilers, HSE 1989, ISBN 0 7176 1028 4

In the most severe cases, a low-water condition can lead to catastrophic failure resulting in major structural damage and in the worst cases an explosion, due to the rapid quenching effect when a sudden surge of boiler water makes direct condition with the overheated surfaces on the flame-side of the fire-tub

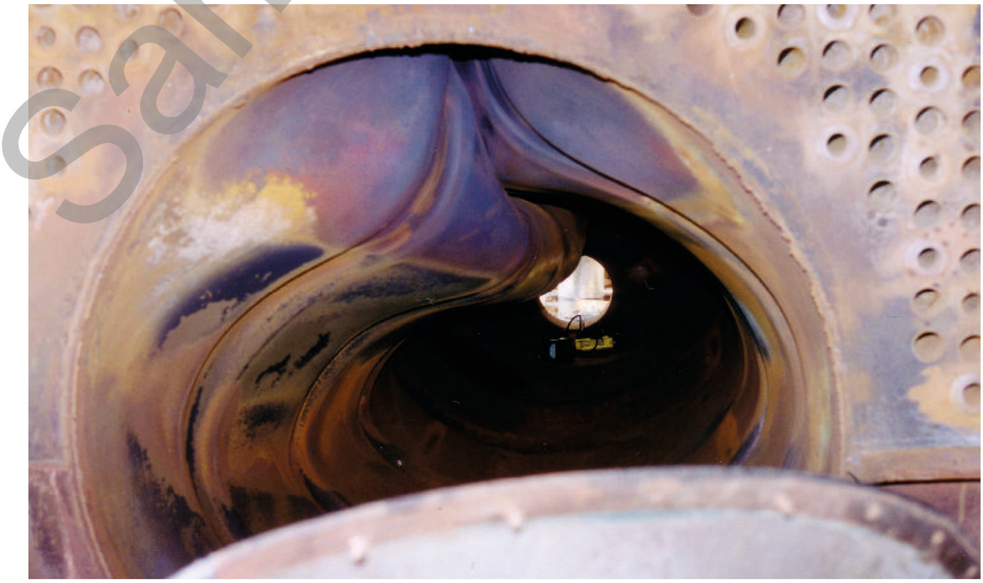


Figure 6.22 View of a collapsed fire-tube caused by overheating resulting from a low water condition.

Examples of Oxygen Pitting - Shell & Fire-tube water-side surfaces

The pitting shown below in Figure 6.43 was detected during an investigation into a fire-tube collapse in a boiler which had been in service for approximately 25 years. The water-side of the boiler had not been subjected to a proper internal examination other than an occasional visual inspection via the top man hole.

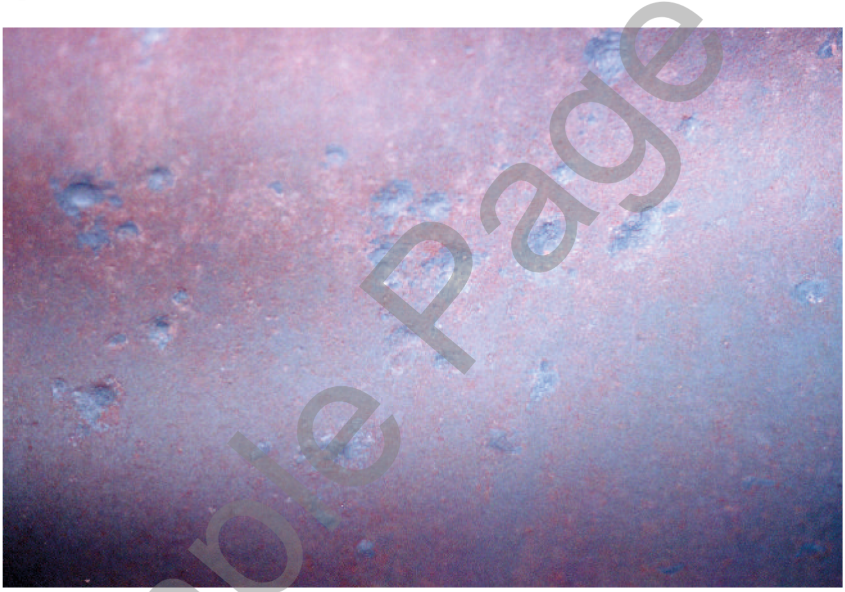


Figure 6.42 Oxygen pitting on the water-side surface of a boiler shell.

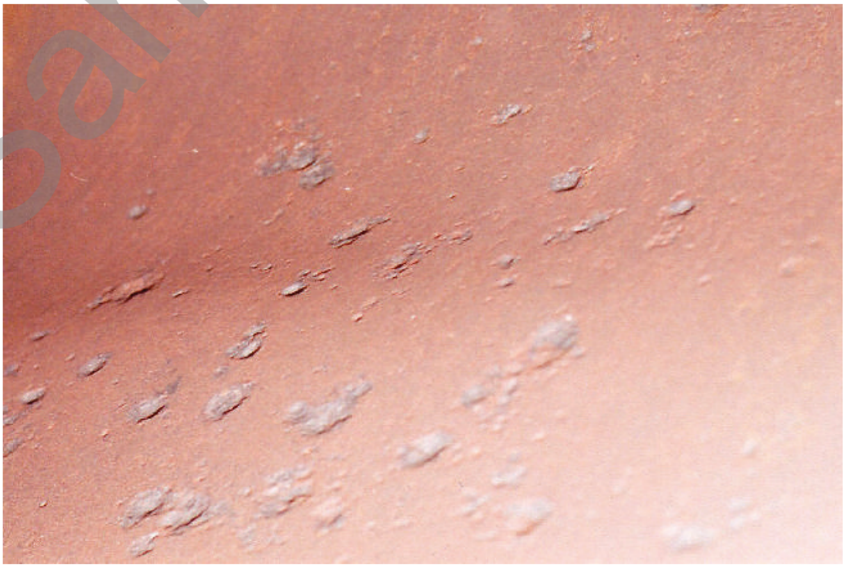


Figure 6.43 Oxygen pitting on the water-side surface of a fire-tube

Examples of Caustic Cracking in a Front End Plate

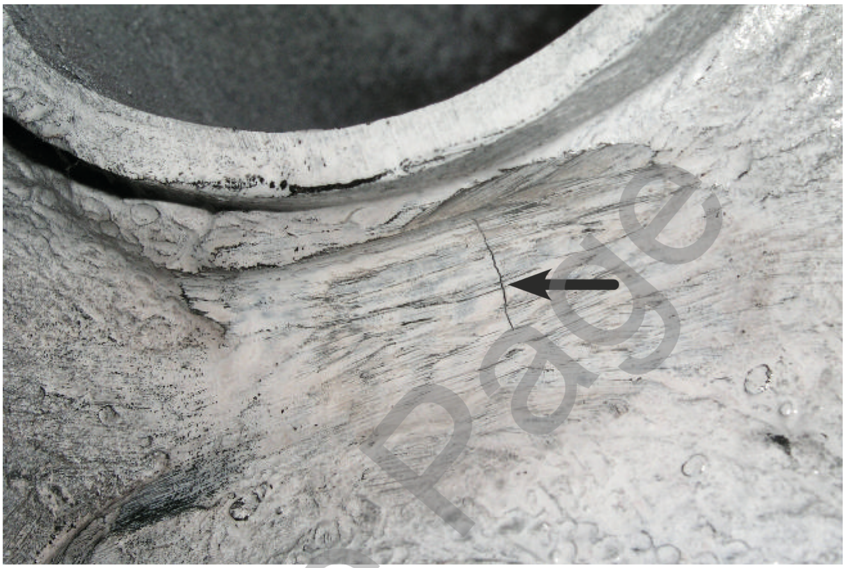


Figure 6.58 Caustic cracking which developed within a few months of commissioning in the end plate between the smoke tubes at the front end of a boiler. (Image courtesy Andrew King)

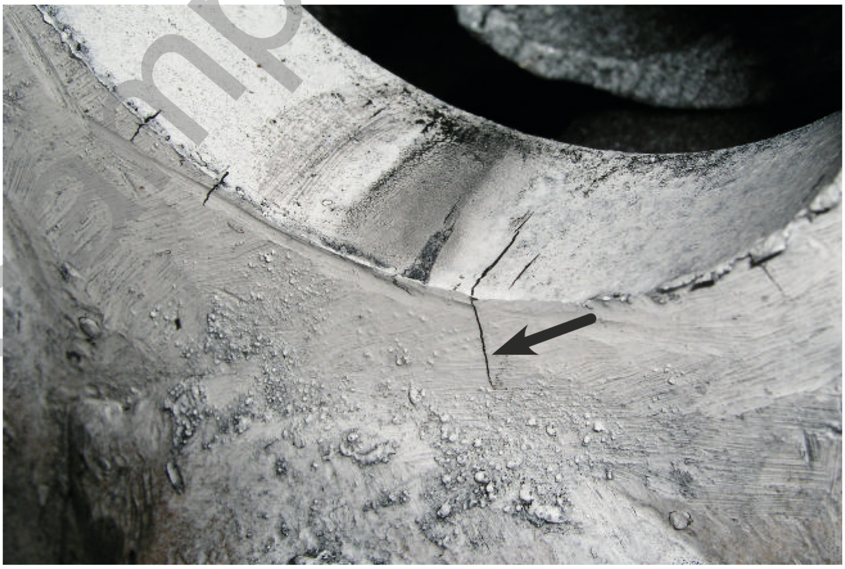


Figure 6.59 Exposed end plate shown opposite following the removal of the smoke tube. Note evidence of multiple cracking which had propagated into the plate from the weld root area. The cracking had not propagated into the tube. (Image courtesy Andrew King)

Areas Where Fatigue Cracking Can Occur In Dry Back Boilers

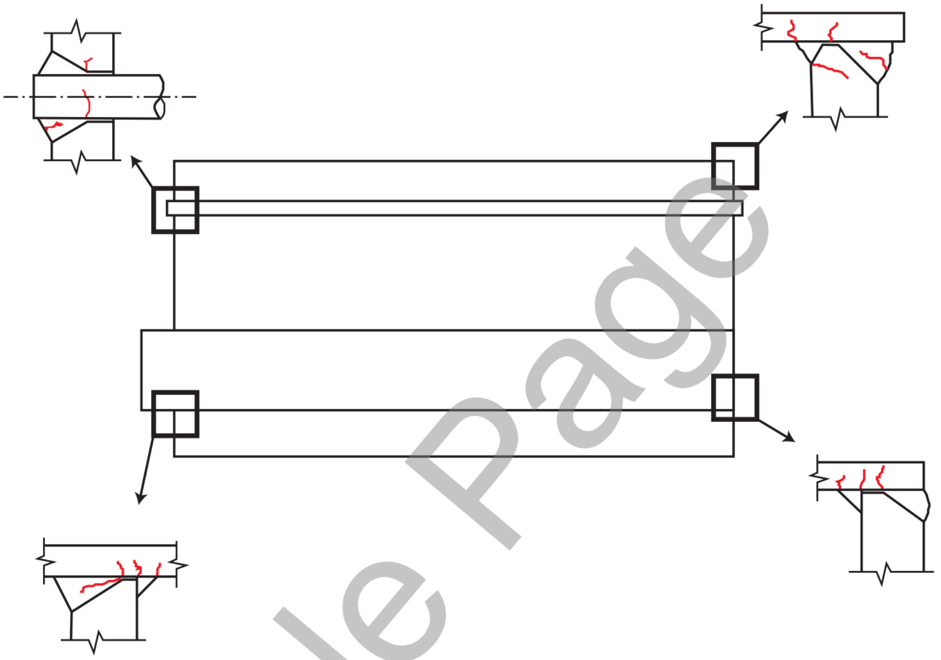


Figure 7.3 Sites where cracking can occur in the welds in a dry back type of boiler

Areas Where Fatigue Cracking Can Occur In Semi-Wet Back Boilers

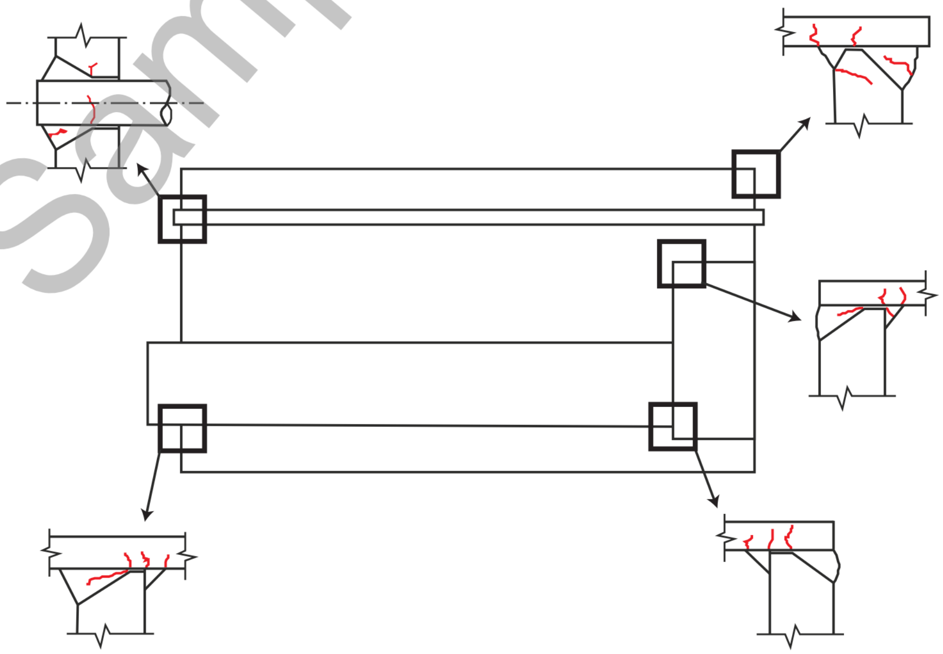


Figure 7.4 Sites where cracking can occur in the welds in a semi-wet back type of boiler.

Microscopic Characteristics of Cracking on the Crown of a Corrugated Fire-Tube

Extreme thermal fatigue conditions can occur where the burner flame impinges directly onto the metal surfaces. An example of this has been the recurring problem with boilers fitted with corrugated furnace tubes, where multiple longitudinal cracking can develop on the crown of the corrugations as shown in Figure 7.16. Both fatigue and thermal fatigue cracks can progress in an intergranular and transgranular mode through the metal, but they generally exhibit a straight wedge-shaped profile as can be seen below in Figure 7.17

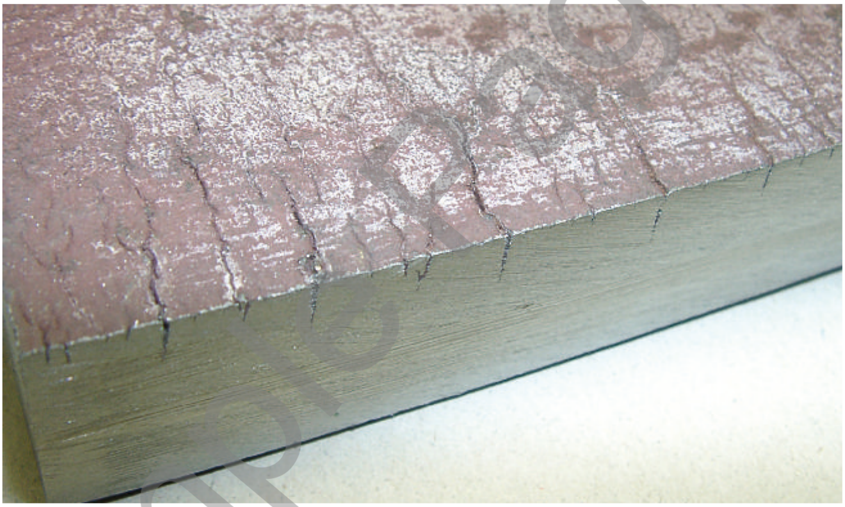


Figure 7.16 Longitudinal cross section of a fire-tube corrugation showing multiple fatigue cracking on the crown area.

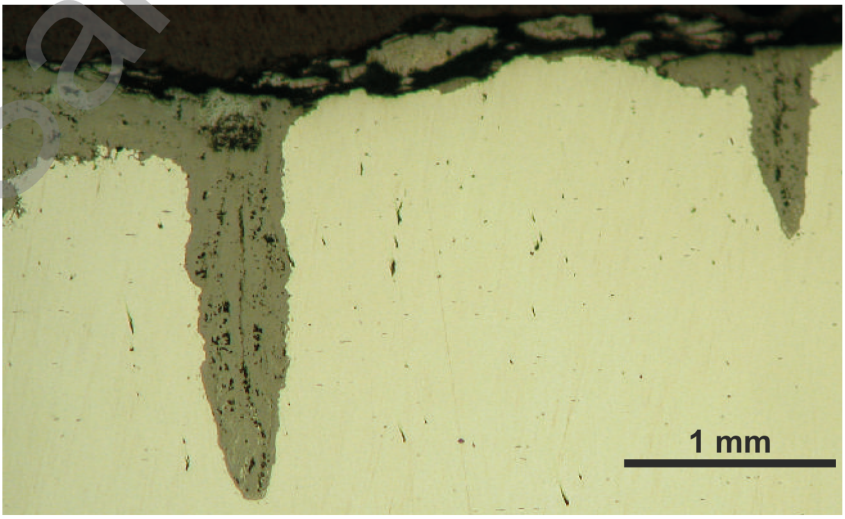


Figure 7.17 Micrograph of a section of the cracked corrugation shown opposite showing two small cracks with a 'v' shaped blunt profile at their tips characteristic of fatigue cracking. Note that both cracks are completely filled with thermal oxides

Typical Ultrasonic Scanning Procedure - End Plate to Shell and Fire-Tube Welds

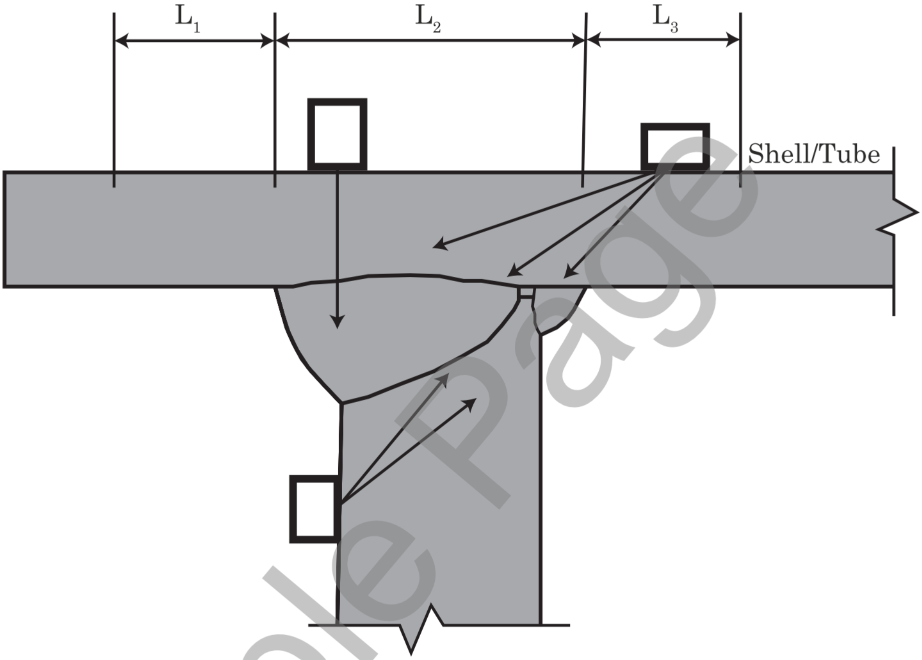


Figure 8.9 Typical compression and shear wave transducer scanning pattern for shell to end plate, end plate to fire-tube and rear access tube welds

Equipment/test Conditions	Test Area	
	Shell side	End plate side
Transducer type	0°,45°,60° & 70° (depending on thickness of plate)	0°,45° & 60°
Scanning zone	L_1= Full skip	Where accessible
	L_2= Between weld cap edges	Where accessible
	L_3= Full skip	Where accessible
Sensitivity	Compression scan: 3rd back wall echo to f.s.h. Shear scan: 2-3mm 'grass' over test range, DAC curve plus 12 - 14 dB (3mm Ø)	Compression scan: 3rd back wall echo to f.s.h. Shear scan: 2-3mm 'grass' over test range, DAC curve plus 12 - 14 dB (3mm Ø)
Sizing technique(s)	6 dB (defect length) and 20 dB drop (defect height), Maximum Amplitude.	6 dB (defect length) and 20 dB drop (defect height), Maximum Amplitude.

Step 5:- Visual and magnetic particle examination of completed weld

Key points:

1. Care needs to be taken when fitting the replacement plate section as there is a risk of distortion during welding which may affect the local circularity of the shell. The completed weld(s) should exhibit a smooth transition without any notches or other defects which may act as stress concentrators. As this type of problem generally occurs on older boilers, particular attention needs to be paid to weld quality as it is likely that the original welds would have been a partial penetration welds. The new welds should be fully penetrating and if necessary should be welded from both sides to form a double-bevel weld.

2. The procedure of excavating a crack in the root area of a weld from the outside surface of the shell is not recommended. The main reason for this is that it is very difficult to both ensure that the crack is fully excavated and to produce the correct type of weld preparation for a new weld.

Shell to End Plate Weld Repair Using the D Plate Method

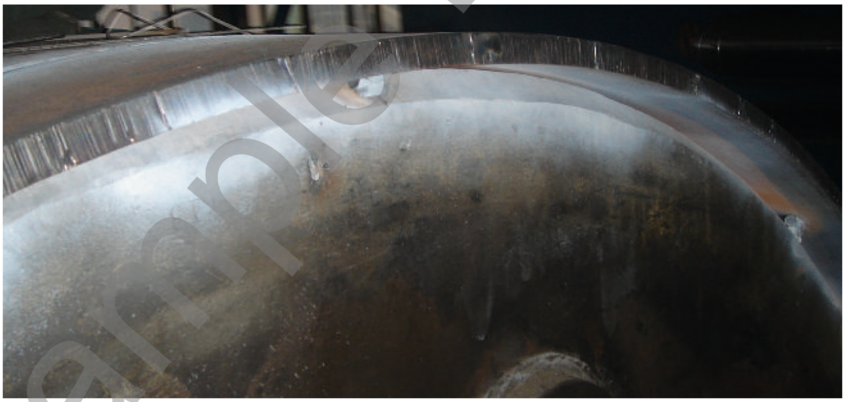


Figure 9.1 'D' plate repair on the upper section of a shell to end plate weld.
(Photo courtesy John Guerin (P J Guerin Ltd, Ireland))

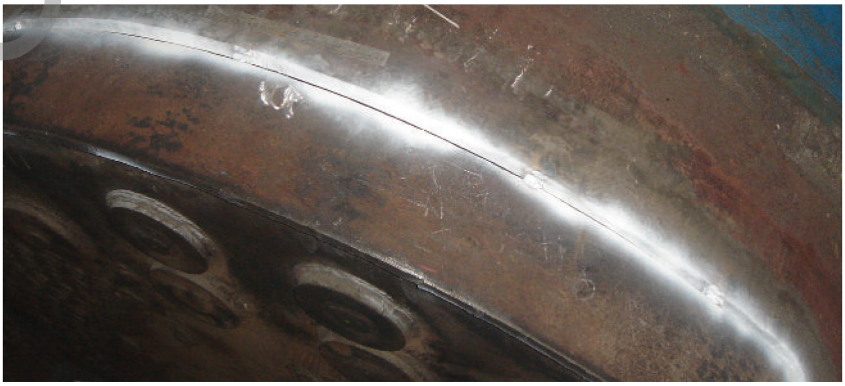


Figure 9.2 Overhead view of the 'D' plate section shown in Figure 9.1 stitch welded into position for welding.
(Photo courtesy John Guerin (P J Guerin Ltd, Ireland))

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